DOE/SF/00824--T17 MASTER

Program: Sodium Technology	
AEC Task: 1 — FFTF Support Work — Friction Tests	
Program Manager: G. W. Meyers	**Project Manager:** J. G. Asquith
Reporting Period: October-December 1973	**Category:** HN 04 01 01.5
General Order: 06507 **Subaccount:** 11100	**189a Number:** 13625

Principal Investigators: W. J. Kurzeka, R. M. Oliva, P. Horton

AM03-76SF00824

I. PROJECT OBJECTIVES

The objective of this program is to conduct friction screening tests in an environment of high-temperature, high-purity liquid sodium or sodium vapor to: (1) develop backup materials, processes, and vendors for core component wear pads, (2) investigate material treatments and coatings for improvement of wear behavior of common LMFBR structural materials, (3) evaluate weld-deposited hardfacings and/or prefabricated bearing materials for use in long-term, high-temperature, high-fluence regions, (4) evaluate bearing materials with a low potential for change in surface composition due to corrosion or mass transfer effects, and (5) develop statistical confidence in friction values for selected material combinations.

II. MAJOR ACCOMPLISHMENTS DURING FISCAL YEAR 1974

Friction testing of the eighth and ninth test matrices was completed. Data for the eighth matrix were reduced, and were presented in the Quarterly Technical Progress Report, AI-AEC-13113; data for the ninth matrix are being reduced. These data are a continuation of and supplement the material screening effort which to date has evaluated nine matrices, of 18 couples each, in sodium and/or sodium vapor to the temperature, surface loading, and wear conditions specified by HEDL (see Annual Technical Progress Report, AI-AEC-13110).

Preparation of test specimens for the tenth matrix has been started. This matrix, which will be evaluated in sodium vapor, introduces certain materials or coatings which are new to the AI friction program. Procurement of these necessary materials and/or coating services is in progress.

Machined couples (seven each, riders and plates) were sent to HEDL for application of sputtered and/or ion coatings, which will be applied per their direction onto the Type 316 stainless steel substrates. These articles are expected to be utilized in the eleventh or twelfth matrices.

The friction test program was reviewed at a general meeting at AI on November 8 and 9, 1973, with representatives of AEC, HEDL, ARD, AI, LMEC, AMCO, GE, and ANL in attendance. The content of the tenth AI friction matrix was formulated at this meeting. A complete package of data from the eighth matrix was presented to HEDL for inclusion in the interim topical report being prepared by HEDL.

III. PROGRESS DURING REPORT PERIOD

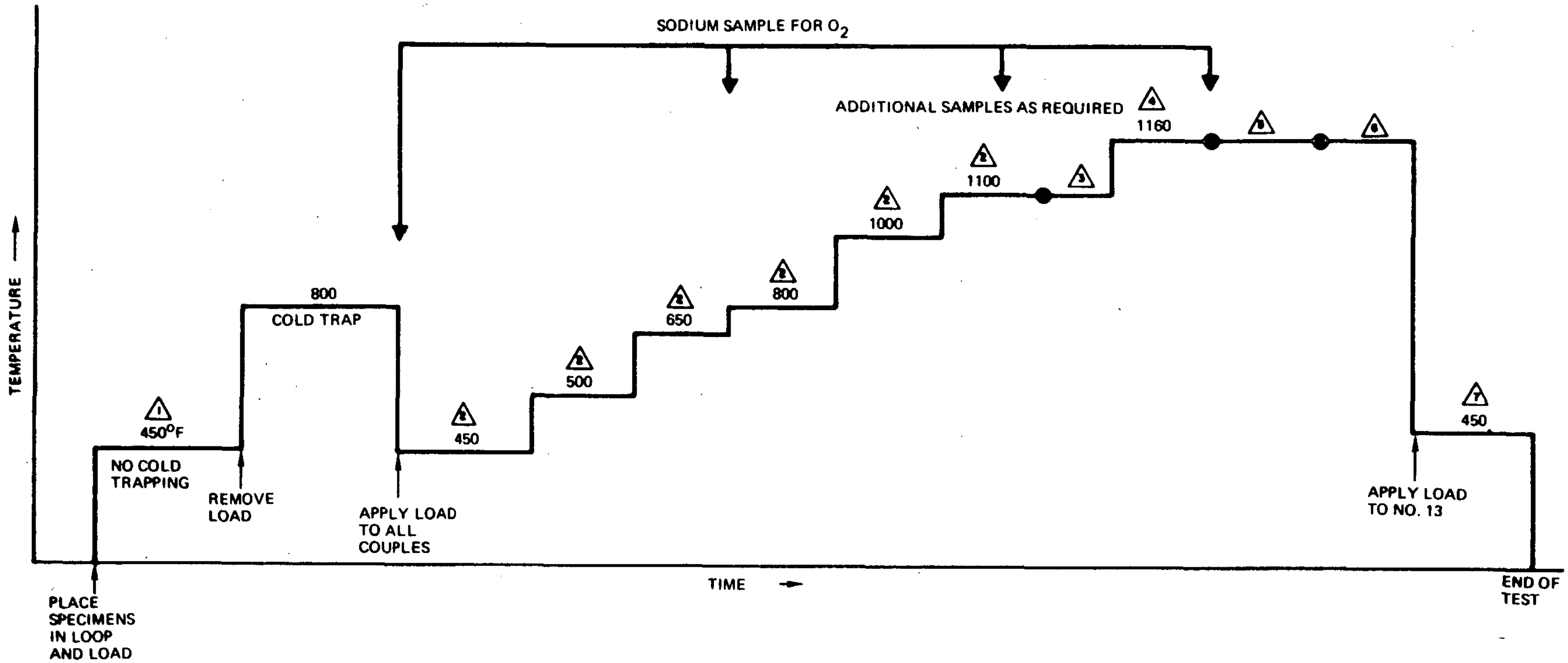
Testing of the eighth friction matrix (Table 1) was completed on October 15, 1973, and followed the temperature test sequence noted on Figure 1. The temperature sequence was performed without incident, and without deviation from the noted operational procedures. Sodium samples taken periodically during the test and analyzed for oxygen content per ANL/ST-6 showed that the oxygen level remained below the 5 ppm maximum allowable content.

Breakaway, static, and dynamic friction coefficients were measured, as required, at each temperature level. A summary of these data is shown in Table 2. The breakaway friction coefficient was computed, using the value of the load which was required to initiate movement on the first wear cycle following the dwell period. The static and dynamic friction coefficients shown represent an average of the values observed during Wear Cycles 2 to 5 with those measured during Cycles 20 to 25. These various friction coefficients are plotted in Figure 2 to show each couple's friction characteristics vs the combination of temperature and wear cycle accumulation. (An explanation of the coating material identifications and the symbol descriptions used in Figure 2 is given in Tables 3 and 4, respectively.) Photographs taken of the eighteen couples after test appear in Figure 3. Test data are also presented in the summary table format (specified by HEDL) in Table 5.

TABLE 1

FRICTION MATRIX No. 8

	Rider	Plate	Load (psi)	Maximum Temperature (°F)
1.	Aluminized Hastelloy C	Aluminized Hastelloy C	800	1160
2.	Chromized Hastelloy C	Chromized Hastelloy C	800	1160
3.	Chromized-Carburized Type 304 SS	Aluminized Inconel 718	800	1160
4.	Chromized-Carburized Hastelloy C	Chromized-Carburized Hastelloy C	800	1160
5.	Aluminized A-286	Aluminized A-286	800	1160
6.	Chromized A-286	Chromized A-286	800	1160
7.	Borided A-286	Borided A-286	800	1160
8.	Chromized-Carburized A-286	Chromized-Carburized A-286	800	1160
9.	Aluminized Type 304 Stainless Steel	Aluminized Inconel 718	800	1160
10.	Chromized Type 304 Stainless Steel	Chromized Type 304 Stainless Steel	800	1160
11.	Borided Type 304 Stainless Steel	Borided Type 304 Stainless Steel	800	1160
12.	Chromized-Carburized Type 304 Stainless Steel	Chromized-Carburized Type 304 Stainless Steel	800	1160
13.	Borided Inconel 718	Borided Inconel 718	800	1160
14.	Chromized-Carburized Inconel 718	Chromized-Carburized Inconel 718	800	1160
15.	Chromized Type 304 Stainless Steel	Aluminized Inconel 718	800	1160
16.	Borided A-286	Aluminized Inconel 718	800	1160
17.	A-286	Aluminized Inconel 718	800	500
18.	Type 316 Stainless Steel (annealed)	Aluminized Inconel 718	300	500



1. APPLY LOAD TO COUPLES, RUB 10 CYCLES
2. AFTER OVERNIGHT DWELL, APPLY 25 WEAR CYCLES
3. AFTER 3-day DWELL MINIMUM, APPLY 25 CYCLES
4. AFTER OVERNIGHT DWELL, APPLY 25 CYCLES
5. AFTER 3-day DWELL MINIMUM, APPLY 25 CYCLES
6. DWELL OVERNIGHT (16-hr MINIMUM) UNDER SPECIFIED LOAD. DO NOT APPLY ANY WEAR CYCLES
7. AFTER A 3-day MINIMUM DWELL, APPLY 25 CYCLES

GENERAL TEST CONDITIONS

1. TEMPERATURE CHANGE OF 50°F/hr (MAX.)
2. STABLE TEMPERATURE ±5°F
3. PLUGGING TEMPERATURE AT EACH TEMPERATURE LEVEL
4. O_2 CONTENT TO BE 5 ppm OR LESS THROUGHOUT TEST
5. OVERNIGHT DWELLS TO BE 16 hr MINIMUM

6507-471338

Figure 1. Temperature Sequence for Eighth Test Matrix

TABLE 2

FRICTION TEST No. 8

Rider	Plate	Contact Pressure (psi)	Breakaway(B) Static(S)* Dynamic(D)*	Friction Coefficient 450F † 0-10 Cycles	450F △ 11-35 Cycles	500F △ 36-60 Cycles	650F △ 61-85 Cycles	800F △ 86-110 Cycles	1000F △ 110-135 Cycles	1100F △ 136-160 Cycles	1100F ▲ 161-185 Cycles	1160F △ 185-210 Cycles	1160F ▲ 211-235 Cycles	450F ▲ 235-260 Cycles
1. Aluminized Hastelloy C	Aluminized Hastelloy C		B	0.30	0.36	0.38	0.43	0.56	0.67	0.88	1.00	1.02	1.24	1.10
		800	S	0.24	0.40	0.39	0.44	0.38	0.31	0.35	0.26	0.41	0.26	0.40
			D	0.59	0.41	0.43	0.49	0.46	0.46	0.52	0.44	0.59	0.37	0.47
2. Chromized Hastelloy C	Chromized Hastelloy C		B	0.50	0.34	0.40	0.45	0.46	0.80	0.93	1.12	1.10	1.44	1.43
		800	S	0.18	0.32	0.31	0.36	0.59	0.50	0.52	0.48	0.55	0.48	0.54
			D	0.40	0.39	0.34	0.48	0.63	0.69	0.70	0.65	0.65	0.65	0.68
3. Chromized-Carburized 304 SS	Aluminized Inconel 718		B	0.35	0.37	0.23	0.28	0.34	0.83	0.69	0.93	1.08	1.06	1.10
		800	S	0.30	0.30	0.29	0.28	0.39	0.50	0.33	0.29	0.23	0.20	0.45
			D	0.37	0.37	0.37	0.36	0.52	0.58	0.54	0.48	0.37	0.31	0.58
4. Chromized-Carburized Hastelloy C	Chromized Carburized Hastelloy C		B	0.30	0.47	0.38	0.55	0.60	0.92	0.80	0.95	1.01	1.08	1.28
		800	S	0.15	0.51	0.52	0.52	0.56	0.67	0.41	0.46	0.55	0.50	0.59
			D	0.42	0.48	0.48	0.46	0.59	0.69	0.50	0.51	0.63	0.68	0.84
5. Aluminized A-286	Aluminized A-286		B	0.47	0.50	0.50	0.48	0.65	0.97	0.76	0.80	0.82	0.96	1.38
		800	S	0.35	0.30	0.35	0.36	0.33	0.38	0.41	0.30	0.39	0.42	0.53
			D	0.63	0.28	0.45	0.47	0.50	0.56	0.40	0.47	0.56	0.48	0.70
6. Chromized A-286	Chromized A-286		B	0.21	0.39	0.33	0.30	0.41	0.86	0.88	0.85	1.25	1.56	>2.0
		800	S	0.30	0.33	0.32	0.33	0.38	0.50	0.61	0.58	0.75	0.73	0.50
			D	0.58	0.38	0.41	0.40	0.50	0.74	0.72	0.62	0.88	0.96	0.74
7. Borided A-286	Borided A-286		B	0.43	0.39	0.34	0.39	0.57	>1.7	>2.0	1.80	1.63	1.72	1.88
		800	S	0.50	0.33	0.35	0.31	0.36	0.30	0.32	0.23	0.25	0.31	0.65
			D	0.75	0.36	0.40	0.40	0.50	0.34	0.34	0.33	0.31	0.35	0.79
8. Chromize-Carburized A-286	Chromize-Carburized A-286		B	0.30	0.37	0.39	0.45	0.43	1.00	1.02	0.91	1.15	1.72	>2.0
		800	S	0.27	0.33	0.36	0.36	0.42	0.48	0.45	0.47	0.60	0.68	0.44
			D	0.48	0.37	0.45	0.53	0.50	0.55	0.55	0.55	0.73	0.85	0.67
9. Aluminized 304 SS	Aluminized Inconel 718		B	0.48	0.48	0.49	0.43	0.50	1.07	1.03	1.00	0.70	1.04	0.94
		800	S	0.40	0.40	0.39	0.32	0.38	0.51	0.50	0.33	0.35	0.40	0.57
			D	0.75	0.46	0.44	0.43	0.53	0.61	0.49	0.40	0.39	0.50	0.69
10. Chromized 304 SS	Chromized 304 SS		B	0.31	0.37	0.23	0.27	0.33	0.78	0.63	0.78	1.02	1.54	>2.0
		800	S	0.33	0.33	0.31	0.28	0.34	0.45	0.49	0.51	0.70	0.86	0.40
			D	0.48	0.36	0.41	0.41	0.48	0.60	0.41	0.55	0.73	0.83	0.53
11. Borided 304 SS	Borided 304 SS		B	0.22	0.13	0.25	0.22	0.25	0.87	1.40	1.80	1.18	1.62	1.68
		800	S	0.13	0.20	0.16	0.13	0.15	0.22	0.36	0.47	0.77	0.52	0.67
			D	0.37	0.28	0.23	0.27	0.29	0.39	0.40	0.41	0.55	0.69	0.74
12. Chromize-Carburized 304 SS	Chromize-Carburized 304 SS		B	0.30	0.50	0.27	0.35	0.38	0.90	0.73	0.60	1.19	1.80	0.90
		800	S	0.21	0.31	0.32	0.32	0.37	0.41	0.51	0.41	0.65	0.69	0.62
			D	0.43	0.36	0.38	0.36	0.45	0.56	0.64	0.65	0.85	0.81	0.70
13. Borided Inconel 718	Borided Inconel 718		B	0.21	0.24	0.23	0.18	0.37	1.07	1.55	>2.0	1.63	1.88	>2.0
		800	S	0.08	0.18	0.20	0.20	0.20	0.23	0.31	0.25	0.21	0.29	0.82
			D	0.30	0.24	0.26	0.27	0.32	0.31	0.47	0.34	0.30	0.43	0.81
14. Chromize-Carburized Inconel 718	Chromize-Carburized Inconel 718		B	0.20	0.26	0.54	0.40	0.40	0.72	0.88	0.97	1.03	1.14	2.00
		800	S	0.15	0.31	0.42	0.36	0.38	0.39	0.51	0.55	0.50	0.70	0.70
			D	0.35	0.39	0.44	0.42	0.45	0.49	0.57	0.56	0.54	0.58	0.82
15. Chromized 304 SS	Aluminized Inconel 718		B	0.30	0.25	0.30	0.25	0.35	0.96	0.92	1.05	1.20	1.48	1.04
		800	S	0.27	0.31	0.28	0.25	0.30	0.34	0.20	0.27	0.32	0.38	0.51
			D	0.50	0.34	0.33	0.35	0.44	0.44	0.38	0.35	0.40	0.44	0.62
16. Borided A-286	Aluminized Inconel 718		B	0.26	0.39	0.32	0.40	0.42	1.08	1.52	1.48	1.54	1.84	1.04
		800	S	0.20	0.30	0.26	0.29	0.31	0.24	0.43	0.37	0.43	0.40	0.02
			D	0.48	0.36	0.34	0.35	0.38	0.30	0.44	0.38	0.48	0.50	0.71
17. A-286	Aluminized Inconel 718		B	0.21	0.30	0.35								1.06
		800	S	0.28	0.34	0.31§	← No friction cycles run above 500F →							0.54
			D	0.50	0.39	0.43§								0.72
18. 316 SS (Annealed)	Aluminized Inconel 718		B	0.15	0.23	0.30								0.73
		300	S	0.10	0.27	0.26	← Zero load, no friction cycles above 500F →							0.57
			D	0.41	0.40	0.44								0.94

△ *Measurements made after overnight dwell (minimum)*
▲ Measurements made after 3 day dwell (minimum)
* Average observed during cycles 2-10 and 19-24
† Prior to Cold Trapping
§ 150 cycles run

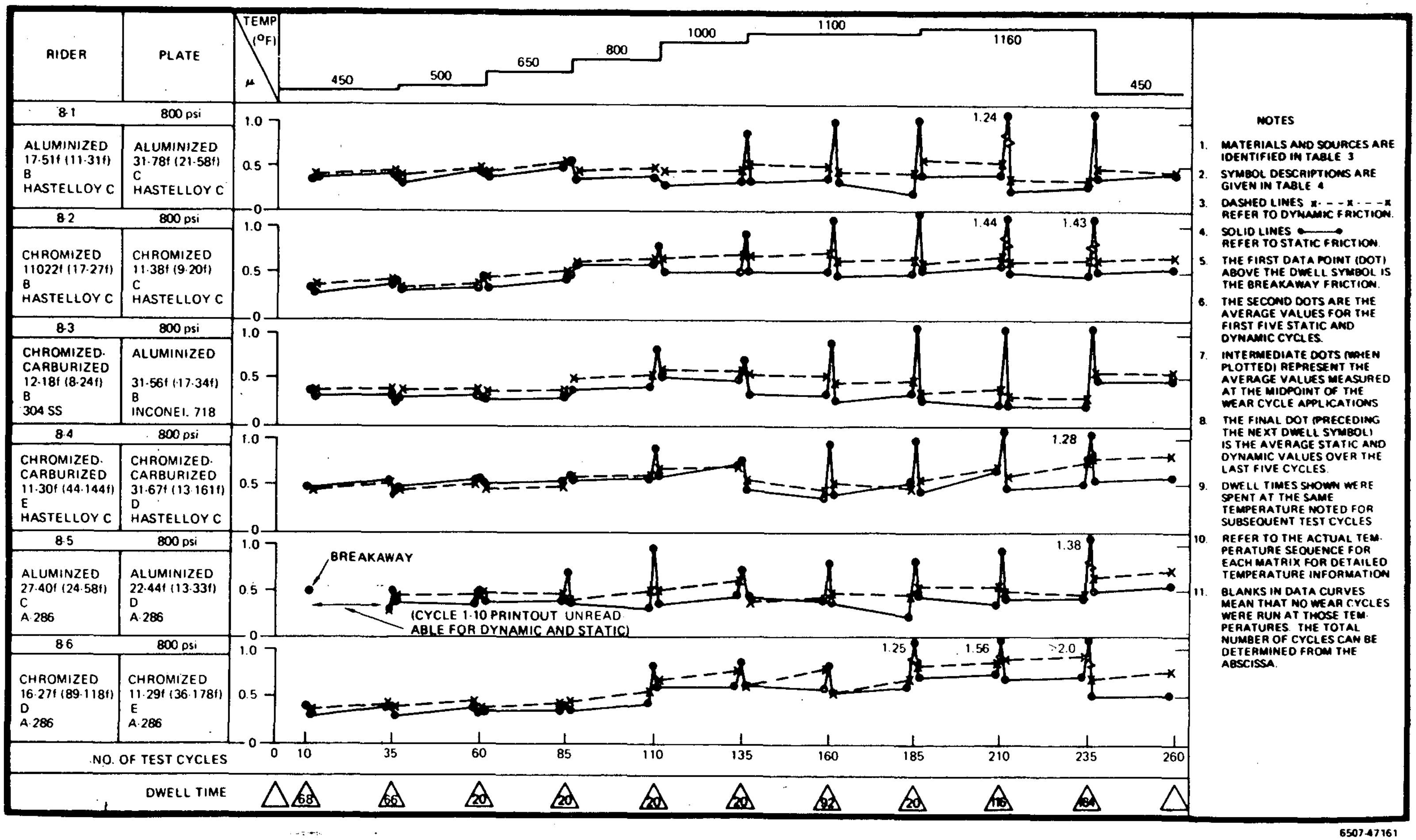


Figure 2. Friction Matrix No. 8 — Friction Coefficients vs Wear Cycles (Sheet 1 of 3)

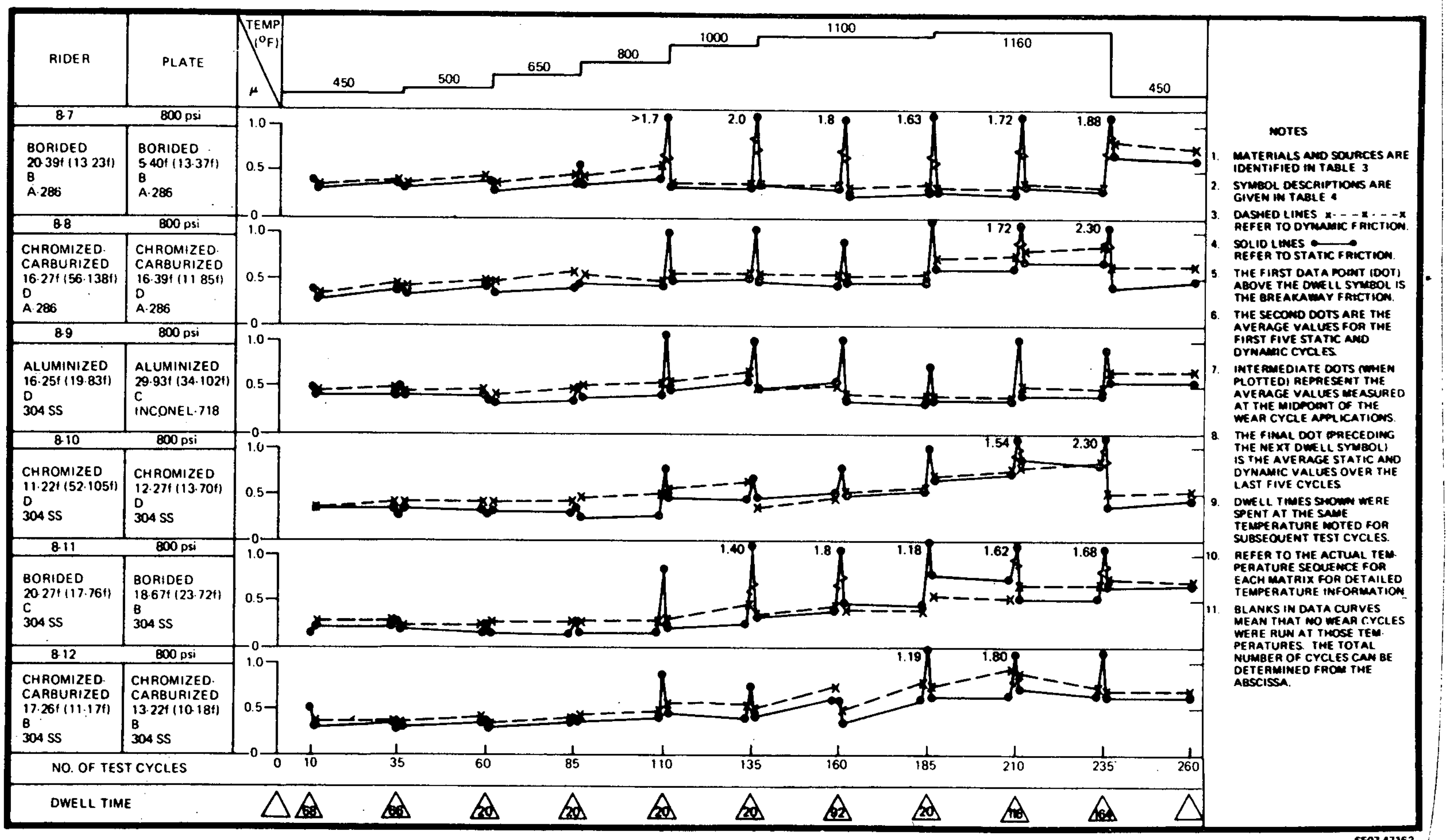


Figure 2. Friction Matrix No. 8 – Friction Coefficients vs Wear Cycles
(Sheet 2 of 3)

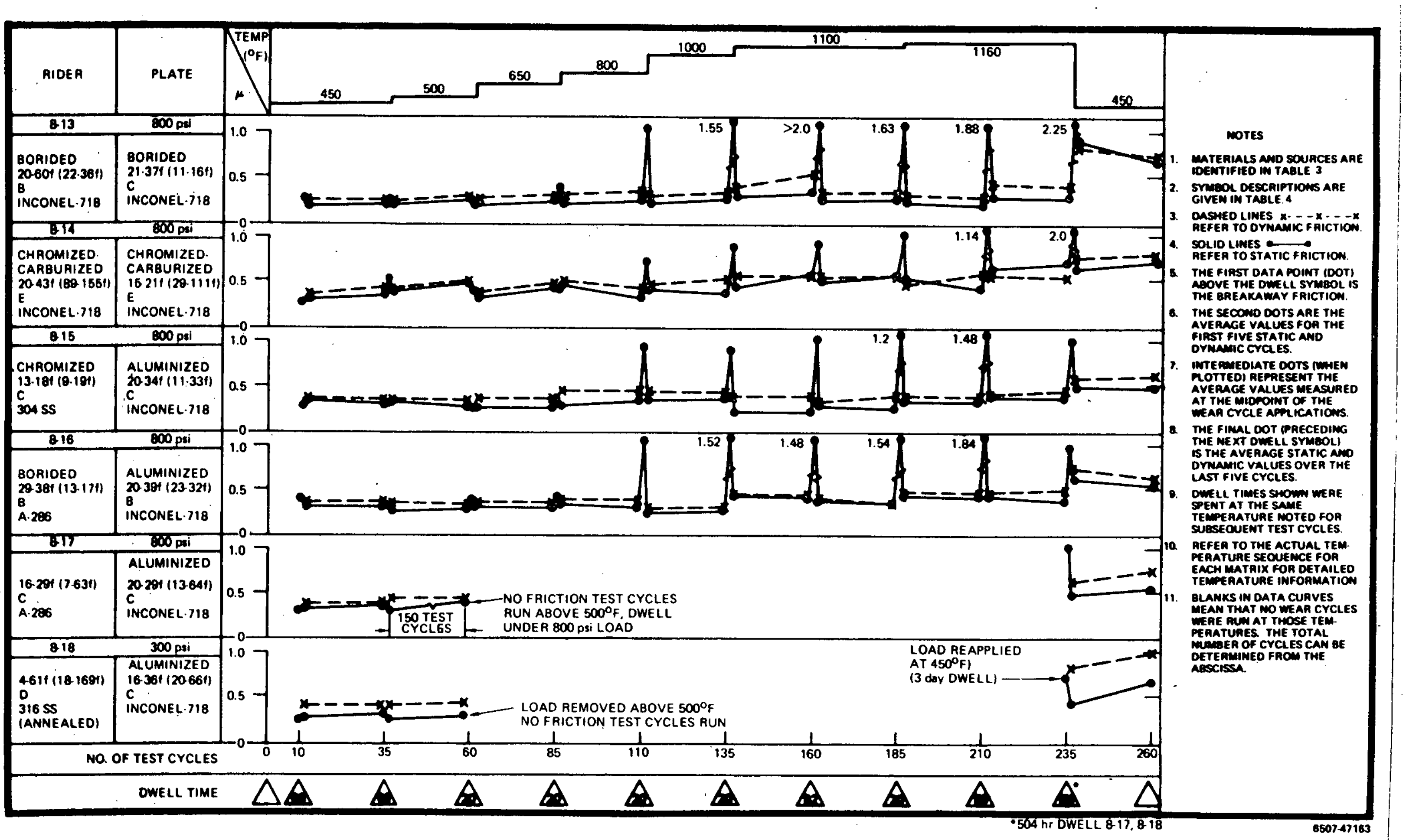


Figure 2. Friction Matrix No. 8 — Friction Coefficients vs Wear Cycles
(Sheet 3 of 3)

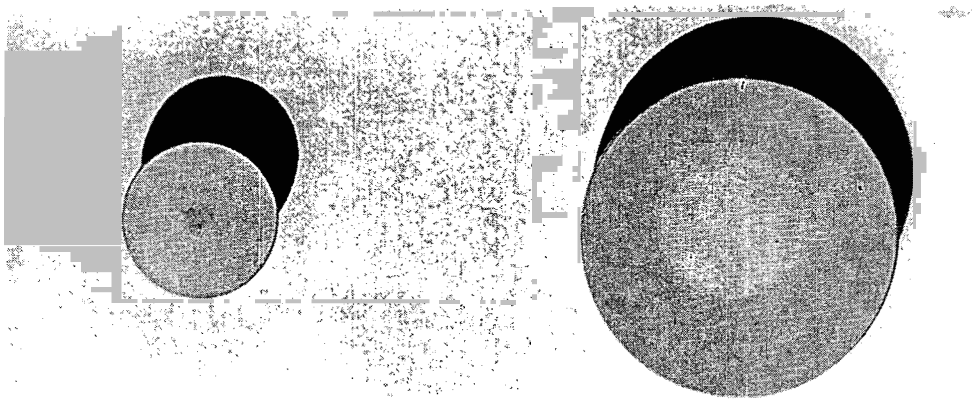
TABLE 3
COATING MATERIAL IDENTIFICATION

Term	Material and Source
A-286	Age-hardened steel with 25% Ni, 15% Cr, and 2% Ti
Aluminize	Diffusion of aluminum into an alloy surface coating. Nickel aluminide rich surface layer in nickel-containing alloys, Chromizing Co.
AM 355	Precipitation-hardened steel with 16% Cr, 4% Ni, and 3% Mo
Chromize	Diffusion of chromium into the surface, creating a chrome-rich layer, Chromizing Co.
CI	Chrome carbide, 15 vol % Inconel 718, applied on Type 316 stainless steel by plasma torch, Union Carbide Corp.
CN-1A	Chrome carbide, 15 vol % Nichrome, deposited on Type 316 stainless steel by detonation gun under "hot gun" conditions, Union Carbide Corp.
CN-1B	Chrome carbide, 15 vol % Nichrome, deposited on Type 316 stainless steel by detonation gun under "cooler gun" conditions, Union Carbide Corp.
Colomony 5	Weld-deposited material – nickel-base alloy with 11% Cr, 4% Fe, 3% Si, and 2% B, Wall Colomony Corp.
Cr-Plate	Hard chrome plate, per Federal Specification QQ-C-320, Class II
Cr_3C_2 - 15 Ni	Cr_3C_2 coating, applied by electric spark discharge method, Mech-Electron Corp.
Electrolize	Proprietary chrome-plating process, Electrolize Corp.
Haynes 273	Weld-deposited material – nickel-base alloy with 5.3% Fe, 17% Mo, and 16% Cr, Stellite Division of Cabot Corp.
Hastelloy C	Nickel-base alloy with 15% Mo and 16% Cr, Union Carbide Corp.
I 718	Inconel 718, International Nickel Corp.
K151A	TiC cermet – 81% TiC, 19% Ni, Kennametal Corp.
K165	TiC cermet – 83% TiC, 8.5% Mo, Kennametal Corp.
LC-1C	Detonation gun coating of CR_3C_2 with 15% NiCr, Union Carbide Corp.
Ni Resist	High nickel base cast iron (with 30% Ni, 2% C, and 2.5% Si) ASTM A439 Type D3A
Stellite 6	Weld-deposited material – cobalt-base alloy with 27% Cr and 5% W, Stellite Division of Cabot Corp.
Stellite 1016	Weld-deposited material – cobalt-base alloy with 32% Cr and 17% W, Stellite Division of Cabot Corp.
TiC-2	TiC - 10% Mo coating, applied by electric spark discharge method, Mech-Electron Corp.
TiC - 10 Mo	TiC - 10% Mo coating, applied by electric spark discharge method, Mech-Electron Corp. (Same as TiC-2)
TiC - 10 Nb	TiC - 10% Nb coating, applied by electric spark discharge method, Mech-Electron Corp.
TM	TiC with 15 wt % Mo, applied by plasma spraying, Union Carbide Corp.
TN	TiC with 15 wt % NiCr, applied by plasma spraying, Union Carbide Corp.
TZM	Molybdenum alloy, with 99% Mo, 0.5% Ti, and 0.08% Zr
17-4 PH	Precipitation-hardened steel with 17% Cr, 4% Ni, and 4% Cu
17-7 PH	Precipitation-hardened steel with 17% Cr, 7% Ni, and 1% Al
CN-1P	Chrome carbide, 15 vol % Nichrome, plasma spray on Type 316 stainless steel, Union Carbide Corp.
CM	Chrome carbide, 20 vol % Mo, plasma spray on Type 316 stainless steel, Union Carbide Corp.
CI-D	Chrome carbide, 15 vol % Inconel, D gun on Type 316 stainless steel, Union Carbide Corp.
Tribaloy 120	NiCoMoSi DuPont coating, flame spray on Type 316 stainless steel, DuPont Corp.
Tribaloy 400	CoMoSiCr DuPont coating, flame spray on Type 316 stainless steel, DuPont Corp.
Tribaloy 125	CoMoSiCr DuPont coating, flame spray on Type 316 stainless steel, DuPont Corp.
Metco 80NS	Chrome carbide with Nichrome, flame spray, Plasma Technology
Metco 81NS-10	Chrome carbide with Nichrome, flame spray, Plasma Technology
Metco 81VF-NS-12	Chrome carbide with Nichrome, flame spray, Plasma Technology
Metco 430-NS-10	Chrome carbide with nickel aluminide binder, flame spray, Plasma Technology
Boride	Diffusion of boron into an alloy surface coating. Chromizing Company
Chromize-Carburize	Carbon-enriched chrome diffusion process. Outer layer 45% chrome (min.) and 0.5% carbon (min.). Chromizing Company

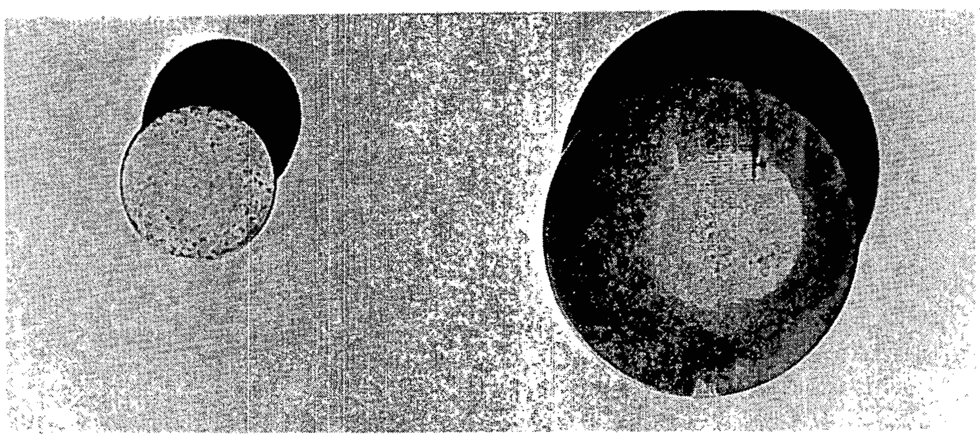
TABLE 4

SYMBOL DESCRIPTIONS

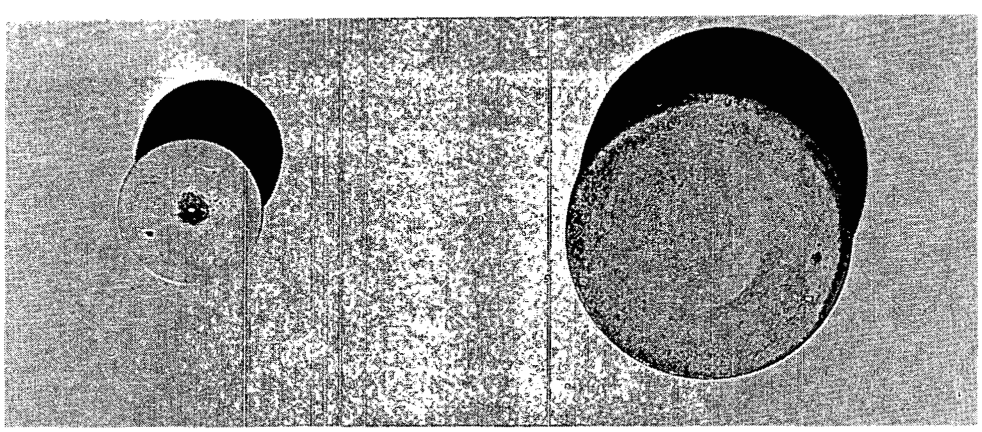
Term	Description
A	Very low wear or essentially no wear
AR	As received
ARDB	As received, dry brush
ARWB	As received, wet brush
B	Low wear (have visible shiny spots, but have no physical surface damage)
B17-4PH	Base material was precipitation-hardened steel with 17% Cr, 4% Ni, and 4% Cu
B304	Base materials was Type 304 stainless steel
B316	Base material was Type 316 stainless steel
B I 718	Base material was Inconel 718
C	Medium wear (slightly scratched)
CDB	Cleaned, dry brush
CWB	Cleaned, wet brush
D	High wear (scratched, along with a few deep cuts)
E	Very high wear (heavily scratched, with or without welding spots)
ESD	Electric spark discharge process by Mech-Electron Corp.
ND	Nondimensional finish. Tyrco wheel process, surface rms > 16
WD	Weld deposit
xxxf	Pre-test surface finish (i.e., 100 f = 100 rms)
(xxxf)	Post-test surface roughness [i.e. (100f) = 100 rms]
√16	Surface finish was 16 rms (or better) ground finish



ALUMINIZED HASTELLOY C
COUPLE 1
ALUMINIZED HASTELLOY C
6507-51274



CHROMIZED HASTELLOY C
COUPLE 2
CHROMIZED HASTELLOY C
6507-51277



CHROMIZED-CARBURIZED TYPE 304 SS
COUPLE 3
ALUMINIZED INCONEL 718
6507-51265

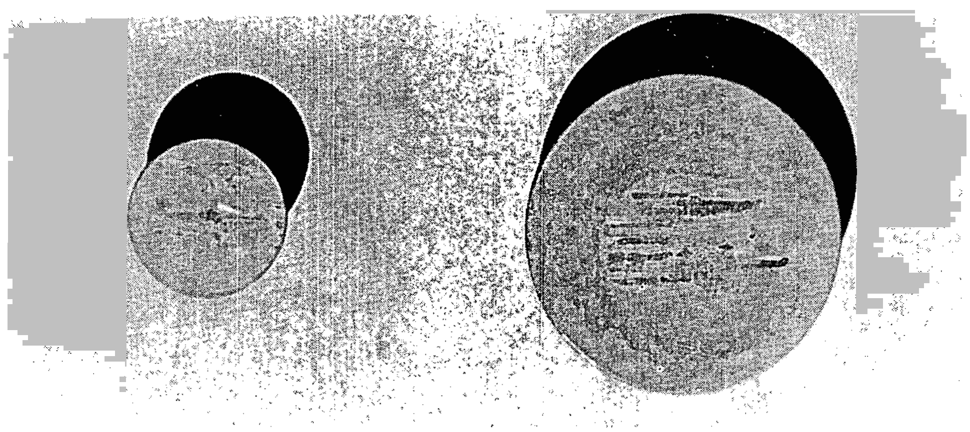
6507-51283

Figure 3. Matrix 8 — Friction Test Specimens
(Sheet 1 of 6)

CHROMIZED-CARBURIZED HASTELLOY C CHROMIZED-CARBURIZED HASTELLOY C

COUPLE 4

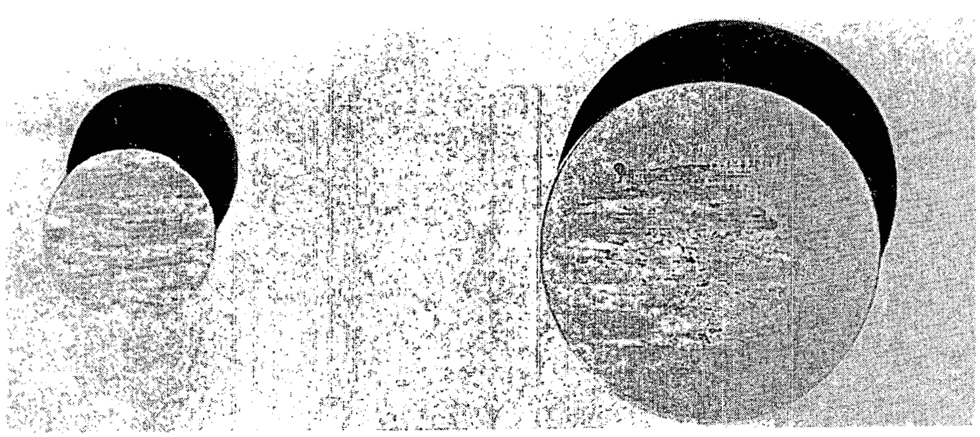
6507-51260



ALUMINIZED A-286 ALUMINIZED A-286

COUPLE 5

6507-51276



CHROMIZED A-286 CHROMIZED A-286

COUPLE 6

6507-51271

6507-51284

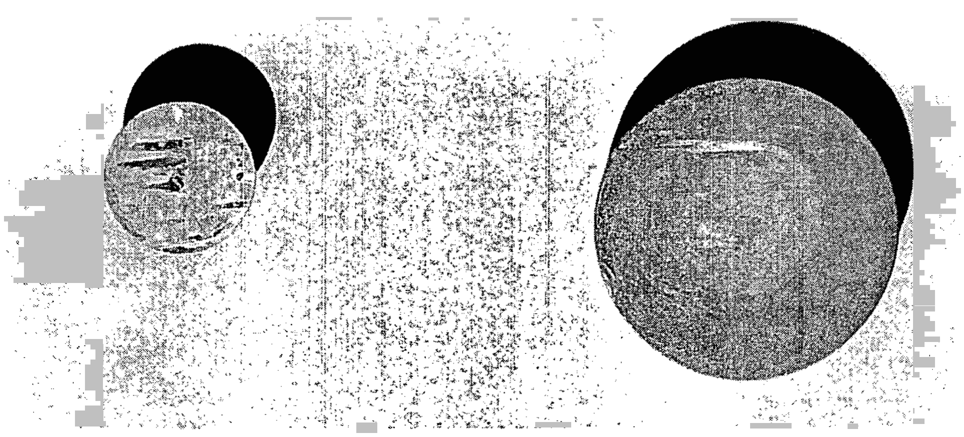
Figure 3. Matrix 8 — Friction Test Specimens
(Sheet 2 of 6)

BORIDED A-286 BORIDED A-286

COUPLE 7 6507-51270

CHROMIZED-CARBURIZED A-286 CHROMIZED-CARBURIZED A-286

COUPLE 8 6507-51272

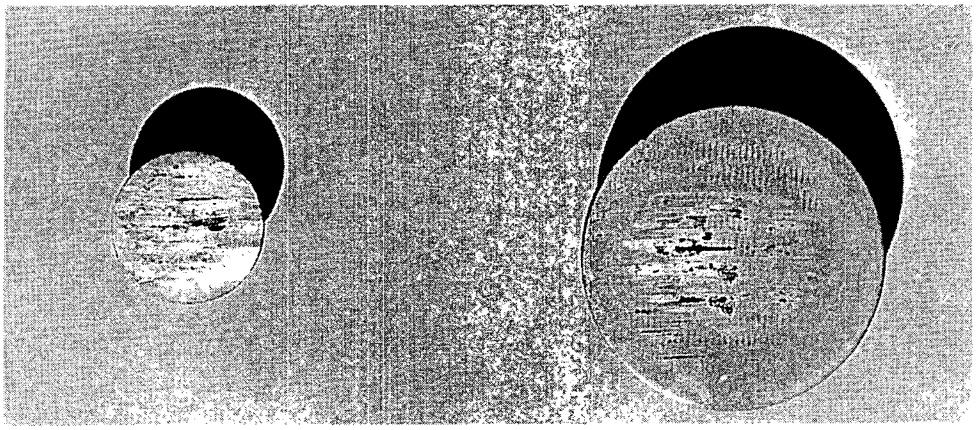


ALUMINIZED TYPE 304 SS ALUMINIZED INCONEL 718

COUPLE 9 6507-51273

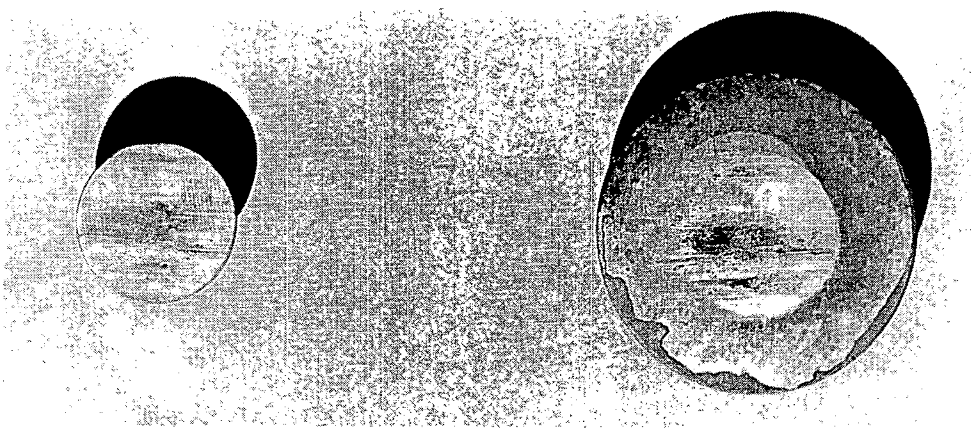
6507-51285

Figure 3. Matrix 8 — Friction Test Specimens
(Sheet 3 of 6)



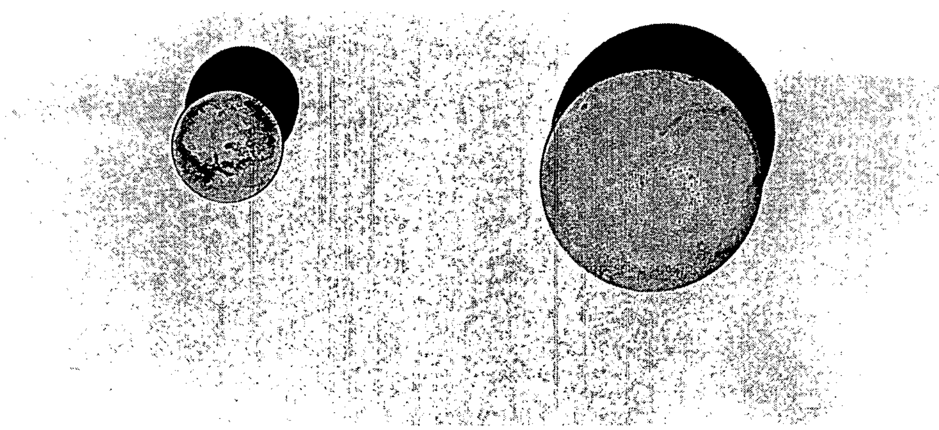
CHROMIZED TYPE 304 SS — COUPLE 10 — CHROMIZED TYPE 304 SS

6507-51259



BORIDED TYPE 304 SS — COUPLE 11 — BORIDED TYPE 304 SS

6507-51267



CHROMIZED-CARBURIZED TYPE 304 SS — COUPLE 12 — CHROMIZED-CARBURIZED TYPE 304 SS

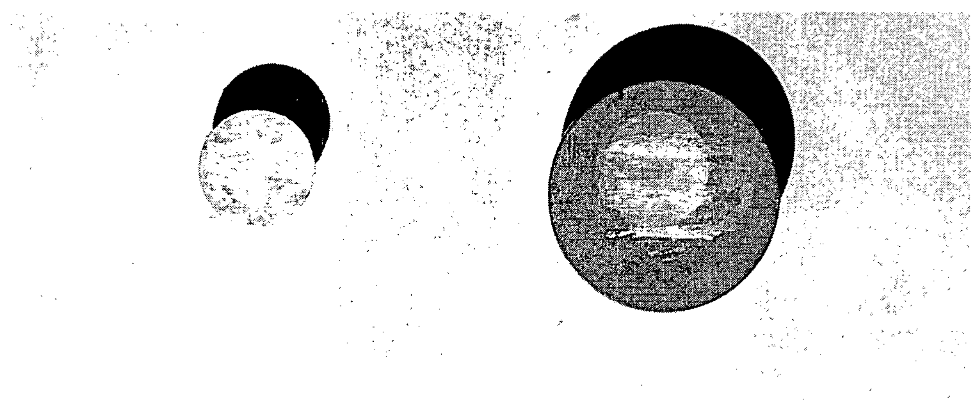
6507-51266

6507-51286

Figure 3. Matrix 8 – Friction Test Specimens
(Sheet 4 of 6)

BORIDED INCONEL 718 BORIDED INCONEL 718

COUPLE 13 6507-51268



CHROMIZED-CARBURIZED INCONEL 718 CHROMIZED-CARBURIZED INCONEL 718

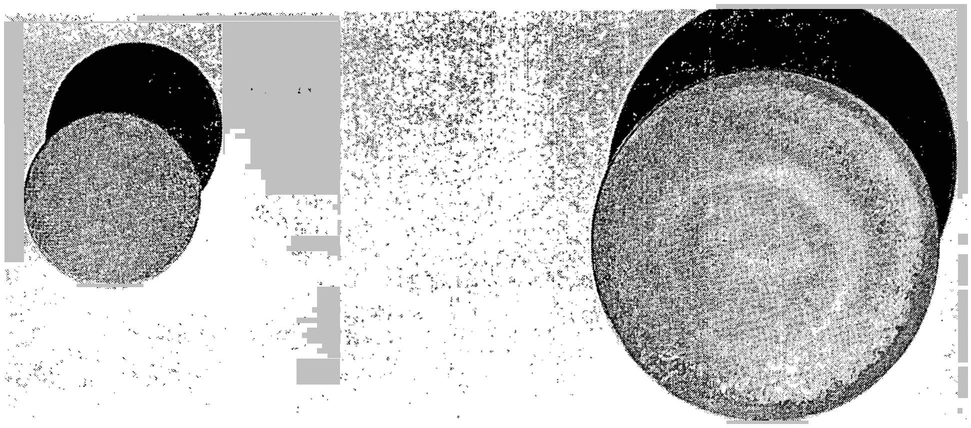
COUPLE 14 6507-51263

CHROMIZED TYPE 304 SS ALUMINIZED INCONEL 718

COUPLE 15 6507-51269

6507-51287

Figure 3. Matrix 8 — Friction Test Specimens
(Sheet 5 of 6)

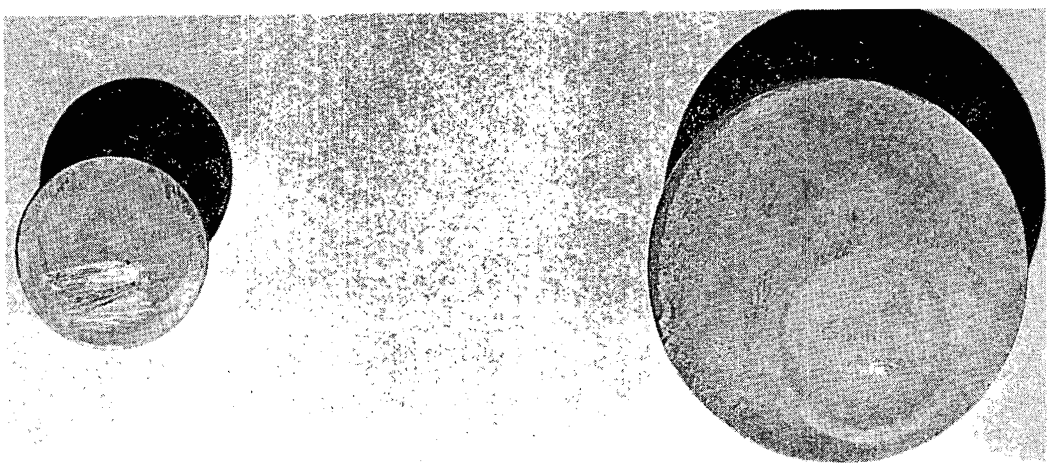


BORIDED A-286

ALUMINIZED INCONEL 718

COUPLE 16

6507-51261

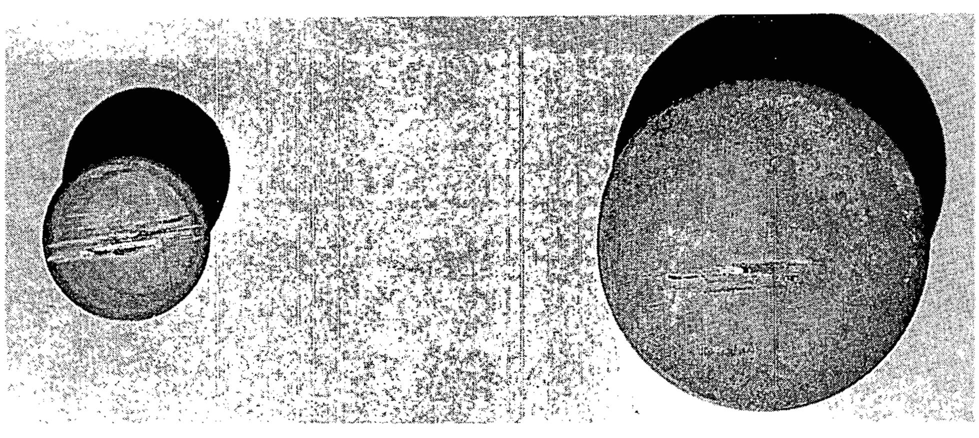


A-286

ALUMINIZED INCONEL 718

COUPLE 17

6507-51262



TYPE 316 SS (ANNEALED)

ALUMINIZED INCONEL 718

COUPLE 18

6507-51264

6507-51288

Figure 3. Matrix 8 — Friction Test Specimens
(Sheet 6 of 6)

TABLE 5

FRICTION MATRIX No. 8
(Sheet 1 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
8-1	Aluminized Hastelloy C	Aluminized Hastelloy C	450	157.1/800	0.07	d/2	35/17.5	68	0.36	0.36	0.42	0.42	0.38	0.43	0.43	Previous experience includes 10/5 at 450° prior to cold trapping
							260/130	164	1.10	0.40	0.43	0.43	0.52	0.52	0.45	Rubbing experience includes prior 35/17.5 at 450° F plus 200/100 at other temp. levels
	17-51f (11-31f)	31-78f (21-58f)	800				110/55	20	0.56	0.40	0.40	0.39	0.40	0.48	0.48	Rubbing experience includes 85/42.5 at lower temperature levels
			1160				210/105	20	1.02	0.45	0.45	0.42	0.54	0.59	0.58	Rubbing experience includes 185/92.5 at lower temp. levels
							235/117.5	116	1.24	0.24	0.27	0.27	0.43	0.43	0.36	Rubbing experience includes 185/92.5 at lower temp. levels plus 25/12.5 at prior 1160°F
8-2	Chromized Hastelloy C	Chromized Hastelloy C	450				35/17.5	68	0.34	0.30	0.38	0.38	0.31	0.42	0.42	Same as 8-1
							260/130	164	1.43	0.51	0.56	0.56	0.62	0.69	0.69	
	11-22f (17-27f)	11-38f (9-20f)	800				110/55	20	0.46	0.52	0.59	0.59	0.55	0.65	0.65	
			1160				210/105	20	1.18	0.49	0.57	0.57	0.58	0.68	0.68	
							235/117.5	116	1.44	0.46	0.50	0.46	0.58	0.66	0.66	
8-3	Chromize-Carburized 304 SS	Aluminized 718 I	450				35/17.5	68	0.37	0.33	0.33	0.31	0.36	0.38	0.38	Same as 8-1
							260/130	164	1.10	0.50	0.50	0.50	0.60	0.60	0.58	
	12-18f (8-24f)	31-56f (17-34f)	800				110/55	20	0.56	0.35	0.40	0.40	0.46	0.54	0.54	
			1160	157.1/800	0.07	d/2	210/105	20	1.24	(1)	0.37	0.36	0.43	0.37	0.36	
							235/117.5	116	1.06	0.52	0.52	0.20	0.40	0.40	0.31	

(1) Initial static friction data unreadable on chart paper.

TABLE 5

FRICTION MATRIX No. 8
(Sheet 2 of 6)

Test			Test Conditions						Friction Results							
	Materials									Static Friction			Dynamic Friction			
Number	Pin	Plate	Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Break-away Friction	Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	Comments
8-4	Chromize-Carburized Hastelloy C	Chromize-Carburized Hastelloy C	450	157.1/800	0.07	d/2	35/17.5	68	0.47	0.38	0.55	0.55	0.37	0.52	0.52	
							260/130	164	1.28	0.64	0.64	0.60	0.79	0.86	0.86	
	11-20f (44-144f)	31-67f (13-161f)	800				110/55	20	0.60	0.48	0.58	0.58	0.52	0.59	0.59	Same as 8-1
			1160				210/105	20	1.01	0.48	0.67	0.67	0.54 (2)	0.70	0.70	
							235/117.5	116	1.08	0.59	0.59	0.52	0.60	0.77	0.77	
8-5	Aluminized A-286	Aluminized A-286	450				35/17.5	68	0.50	(1)	0.30	0.30	(1)	0.28	0.28	
							260/130	164	1.38	0.52	0.56	0.56	0.64	0.73	0.73	
	27-40f (24-58f)	22-44f (13-33f)	800				110/55	20	0.65	0.41	0.41	0.30	0.49	0.50	0.50	Same as 8-1
			1160				210/105	20	0.82	0.59	0.59	0.35	0.58	0.58	0.55	
							235/117.5	116	0.96	0.56	0.56	0.42	0.50	0.50	0.47	
8-6	Chromized A-286	Chromized A-286	450				35/17.5	68	0.39	0.19	0.37	0.37	0.33	0.40	0.40	
							260/130	164	>2.0	0.51	0.51	0.50	0.71	0.79	0.79	
	16-27f (89-118f)	11-29f (36-178f)	800				110/55	20	0.41	0.34	0.41	0.41	0.36	0.55	0.55	Same as 8-1
			1160	157.1/800	0.07	d/2	210/105	20	1.25	0.77	0.77	0.77	0.77	0.89	0.89	
							235/117.5	116	1.56	1.13	1.13	0.75	0.84	0.99	0.99	

(1) Initial values unreadable on chart paper.
(2) Squeaky during first 10 cycles.

TABLE 5

FRICTION MATRIX No. 8
(Sheet 3 of 6)

Test			Test Conditions						Friction Results							Comments
Number	Materials: Pin	Materials: Plate	Temperature (°F)	Load/Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction: Average Initial	Static Friction: Maximum Observed	Static Friction: Average Final	Dynamic Friction: Average Initial	Dynamic Friction: Maximum Observed	Dynamic Friction: Average Final	
8-7	Borided A-286	Borided A-286	450	157.1/800	0.07	d/2	35/17.5	68	0.39	0.36	0.36	0.35	0.35	0.38	0.38	
							260/130	164	1.88	0.73	0.73	0.62	0.72	0.82	0.76	
	20-39f (13-23f)	5-40f (13-37f)	800				110/55	20	0.57	0.36	0.39	0.39	0.36	0.56	0.56	Same as 8-1
			1160				210/105	20	1.63	0.53	0.53	0.34	0.32	0.32	0.31	
							235/117.5	116	1.72	0.53	0.53	0.29	0.33	0.36	0.34	
8-8	Chromize-Carburized A-286	Chromize-Carburized A-286	450				35/17	68	0.37	(1)	0.38	0.38	0.32	0.42	0.42	
							260/130	164	2.3	0.48	0.48	0.48	0.59	0.67	0.67	
	16-27f (56-138f)	16-29f (11-85f)	800				110/55	20	0.43	0.41	0.43	0.41	0.48	0.54	0.46	Same as 8-1
			1160				210/105	20	1.15	0.70	0.70	0.60	0.71	0.78	0.78	
							235/117.5	116	1.72	1.30	1.30	0.68	0.82	0.88	0.88	
8-9	Aluminized 304 SS	Aluminized 7181	450				35/17.5	68	0.48	0.37	0.41	0.41	0.39	0.48	0.48	
							260/130	164	0.94	0.63	0.63	0.56	0.66	0.70	0.70	
	16-25f (19-83f)	29-93f (34-102f)	800				110/55	20	0.50	0.39	0.40	0.40	0.47	0.54	0.54	Same as 8-1
			1160	157.1/800	0.07	d/2	210/105	20	0.70	0.54	0.54	0.35	0.43	0.43	0.38	
							235/117.5	116	1.04	0.48	0.48	0.40	0.53	0.53	0.48	

(1) Value unreadable on chart paper

TABLE 5

FRICTION MATRIX No. 8
(Sheet 4 of 6)

Test: Number	Test: Materials: Pin	Test: Materials: Plate	Test Conditions: Temperature (° F)	Load/ Pressure (lb)/(psi)	Average Velocity (in. /sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Friction Results: Breakaway Friction	Static Friction: Average Initial	Static Friction: Maximum Observed	Static Friction: Average Final	Dynamic Friction: Average Initial	Dynamic Friction: Maximum Observed	Dynamic Friction: Average Final	Comments
8-10	Chromized 304SS	Chromized 304SS	450	157./800	0.07	d/2	35/17.5	68	0.37	0.32	0.33	0.33	0.36	0.36	0.33	
							260/130	164	2.30	0.53	0.53	0.43	0.51	0.54	0.54	
	11-22f (52-105f)	12-27f (13-70f)	800				110/55	20	0.33	0.34	0.37	0.37	0.42	0.50	0.50	Same as 8-1
			1600				210/105	20	1.02	0.99	0.99	0.72	0.69	0.76	0.76	
							235/117.5	116	1.54	1.03	1.03	0.83	0.87	0.87	0.86	
8-11	Borided 304SS	Borided 304SS	450				35/17.5	68	0.13	0.30	0.30	0.21	0.31	0.31	0.28	
							260/130	164	1.68	0.71	0.71	0.70	0.84	0.84	0.73	
	20-27f (17-76f)	18-67f (23-72f)	800				110/55	20	0.25	0.19	0.19	0.16	0.28	0.30	0.30	Same as 8-1
			1600				210/105	20	1.18	0.84	0.84	0.75	0.58	0.58	0.53	
							235/117.5	116	1.62	0.50	0.5	0.52	0.66	0.69	0.68	
8-12	Chromize-Carburized 304SS	Chromize-Carburized 304SS	450				35/17.5	68	0.50	0.32	0.33	0.33	0.33	0.37	0.37	
							260/130	164	0.90	0.61	0.62	0.62	0.71	0.71	0.70	
	17-26f (11-17f)	13-22f (10-18f)	800				110/55	20	0.38	0.36	0.39	0.39	0.40	0.47	0.47	Same as 8-1
			1160	157.1/800	0.07	d/2	210/105	20	1.19	0.72	0.72	0.64	0.66	0.94	0.94	
							235/117.5	116	1.80	0.81	0.81	0.65	0.81	0.89	0.73	

TABLE 5

FRICTION MATRIX No. 8
(Sheet 5 of 6)

Test			Test Conditions						Friction Results							
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			Comments
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
8-13	Borided 718 I	Borided 718 I	450	157.1/800	0.07	d/2	35/17.5	68	0.24	0.20	0.20	0.18	0.22	0.24	0.24	
							260/130	164	2.25	0.96	0.96	0.70	0.89	0.89	0.77	
	20-60f (22-36f)	21-37f (11-16f)	800				110/55	20	0.37	0.22	0.22	0.22	0.18	0.34	0.34	Same as 8-1
			1160				210/105	20	1.63	0.50	0.50	0.19	0.32	0.32	0.30	
							235/17.5	116	1.88	0.51	0.51	0.28	0.41	0.43	0.42	
8-14	Chromize-Carburized 718 I	Chromize-Carburized 718 I	450				35/17.5	68	0.26	0.30	0.34	0.34	0.33	0.42	0.42	
							260/130	164	2.0	0.70	0.73	0.73	0.74	0.84	0.84	
	20-43f (89-155f)	15-21f (29-111f)	800				110/55	20	0.40	0.47	0.47	0.30	0.46	0.50	0.41	Same as 8-1
			1160				210/105	20	1.03	0.61	0.61	0.43	0.62	0.62	0.60	
							235/117.5	116	1.14	0.71	0.72	0.72	0.56	0.58	0.57	
8-15	Chromized 304SS	Aluminized 718 I	450				35/17.5	68	0.25	0.31	0.32	0.29	0.32	0.35	0.32	
							260/130	164	1.04	0.49	0.52	0.52	0.60	0.60	0.63	
	13-18f (9-19f)	20-34f (11-33f)	800				110/55	20	0.35	0.30	0.32	0.32	0.40	0.44	0.44	Same as 8-1
			1160	157.1/800	0.07	d/2	210/105	20	1.20	0.53	0.53	0.32	0.36	0.40	0.39	
							235/117.5	116	1.48	0.53	0.53	0.37	0.37	0.46	0.46	

TABLE 5

FRICTION MATRIX No. 8
(Sheet 6 of 6)

Test			Test Conditions						Friction Results							
Number	Materials		Temperature (°F)	Load/ Pressure (lb)/(psi)	Average Velocity (in./sec)	Stroke Length (Pin diameter)	Rubbing Experienced Number of Strokes/ Distance (in.)	Dwell (hr)	Breakaway Friction	Static Friction			Dynamic Friction			Comments
	Pin	Plate								Average Initial	Maximum Observed	Average Final	Average Initial	Maximum Observed	Average Final	
8-16	Borided A-286	Aluminized 718 I	450	157.1/800	0.07	d/2	35/17.5	68	0.39	0.40	0.40	0.30	0.43	0.43	0.36	Same as 8-1
							260/130	164	1.04	0.71	0.71	0.58	0.69	0.76	0.67	
	29-38f (13-17f)	20-39f (23-32f)	800				110/55	20	0.42	0.41	0.41	0.30	0.38	0.38	0.38	
			1160				210/105	20	1.54	0.81	0.81	0.44	0.48	0.48	0.47	
							235/117.5	116	1.84	0.86	0.86	0.38	0.47	0.52	0.52	
8-17	A-286	Aluminized 718 I	450				35/17.5	68	0.30	0.31	0.37	0.37	0.34	0.40	0.40	Rubbing experience includes 10/5 at 450°F prior to cold trapping
							210/105	504	1.06	0.61	0.61	0.58	0.69	0.78	0.78	Rubbing experience includes prior 35/17.5 at 450°F plus 150/75 at 500°F
	16-20f (7-63f)	20-29f (13-64f)	500(1)	157.1/800			185/92.5	70	0.35	0.37	0.40	0.40	0.35	0.48	0.48	Rubbing experience includes 35/17.5 at 150°F
	Annealed 316SS	Aluminized 718 I	450	58.9/300			35/17.5	68	0.23	0.29	0.29	0.29	0.37	0.41	0.41	Rubbing experience includes 10/5 at 150°F prior to cold trapping
							85/42.5	504	0.73	0.90	0.90	0.70	0.98	1.02	1.02	Rubbing experience includes prior 35/17.5 at 450°F plus 25/12.5 at 500°F
	4-61f (18-169f)	16-36f (20-66f)	500(2)	58.9/300	0.07	d/2	60/30	70	0.30	0.30	0.30	0.30	0.45	0.47	0	Rubbing experience includes 35/17.5 at 450°F

(1) No cycles run above 500°F. 150 total cycles run at 500°F. Load remained on couple at all temperatures above 500°F.
(2) No cycles or data taken above 500°F. Load removed above 500°F.

The borided couples (No. 7 — borided A-286 vs itself, No. 11 — borided Type 304 stainless steel vs itself, No. 13 — borided Inconel 718 vs itself, and No. 16 — borided A-286 vs aluminized Inconel 718) showed very low friction coefficients below 800° F. Above 800° F, none of the couples displayed static or dynamic friction coefficients above 0.8. However, all were characterized by consistently high breakaway values. Little or no surface deformation occurred on any of the specimens.

The chromized-carburized material, when tested against itself, performed badly, in that significant surface wear and damage was evident on most couples. Three specimens (No. 4 — chromized-carburized Hastelloy C vs itself, No. 8 — chromized-carburized A-286 vs itself, and No. 14 — chromized-carburized Inconel 718 vs itself) showed severe wear on both the riders and plates. An exception to this trend was shown by No. 12 — chromized-carburized Type 304 stainless steel vs itself, which showed little or no wear. A study of the friction plots shows no outstanding friction performance for any of the four couples at any temperature ranges. However, when chromized-carburized Type 304 was tested against aluminized Inconel 718 (Couple 3), consistently low friction values resulted over the entire temperature range, and neither part sustained significant wear (a small area at the center of the aluminized Inconel 718 rider was polished, apparently due to a high spot on the surface). Breakaway values at 1100 and 1160° F, and at 450° F (after the high-temperature testing), for this couple were in the range of 1.0 to 1.1.

The only couple having a chromized surface that did not experience moderate to heavy surface wear was No. 2 — chromized Hastelloy C vs itself. Couple No. 6 — chromized A-286 vs itself, and No. 10 — chromized Type 304 vs itself, experienced severe wear or surface deformation on both the riders and plates. Moderate wear was evident on Couple No. 15, which matched chromized Type 304 against aluminized Inconel 718. In this case, the chromized rider experienced the damage, and the aluminized plate was relatively unaffected. Of this group, Couple No. 15 was the best performer, as far as friction was concerned, inasmuch as it displayed static and dynamic friction coefficients at 0.4 or less over the entire temperature range. Breakaway values at high temperature, however, were as high as 1.48.

Seven couples evaluated aluminized coatings on one or both test parts. Generally, the static and dynamic friction coefficients did not exceed 0.5, over the bulk of the entire temperature range, but all showed the undesirable high-temperature breakaway peaks. No wear was evident on Couple No. 1 — aluminized Hastelloy C vs itself, or on Couple No. 16 — borided A-286 vs aluminized Inconel 718. Light wear occurred on both the rider and plate of Couple No. 5 — aluminized A-286 vs itself; while, on Couple No. 9, moderate wear occurred on the aluminized Type 304 rider, but not on the aluminized Inconel 718 plate. The remaining couples [No. 15 — chromized Type 304 vs aluminized Inconel 718, No. 17 — A-286 vs aluminized Inconel 718, and No. 18 — Type 316 stainless steel (annealed) vs aluminized Inconel 718] all sustained moderate to heavy surface damage, but primarily on the nonaluminized surface only. All of the preceding observations of wear are based on visual inspection and evaluation. No metallurgical examinations were made of the coating condition or depth, or of the type and extent of wear. It should be additionally noted that, when evaluating the results, it is important to take into account that a complete understanding of the intended material application, the operating temperature in service, the number of operational cycles, the tolerable friction coefficients in service, the amount of surface deformation (wear permissible over the components' anticipated useful lifetime), long-term corrosion resistance, mechanical strength properties, irradiation effects, and ability to withstand thermal cycling are all necessary to properly and sensibly apply the test results. HEDL will therefore perform the final evaluation of the results of these screening tests, through the coordination and interpretation of results from all of the friction test programs being currently conducted by AI, HEDL, LMEC, and ARD.

In late November, when it became apparent that HEDL's vendor would be unable to provide (on an acceptable schedule) four specimens with sputtered coatings for the ninth matrix, and that the Chromizing Company would be unable to furnish (on time) a satisfactory borided surface on Hastelloy C material, a revised ninth matrix was formulated by HEDL. The new matrix designation is shown in Table 6. AI prepared the test specimens and/or obtained the necessary surface coatings as required. Following pretest inspection and surface finish measurements, photographing, and cleaning, the couples were mounted

TABLE 6

FRICTION MATRIX No. 9

Couple No.	Rider	Plate	Load (psi)
1	Tribaloy 400 (WD)	Tribaloy 400 (WD)	800
2	Tribaloy 800 (PC)	Tribaloy 800 (PC)	800
3	Tribaloy 700 (PC)	Tribaloy 700 (PC)	800
4	Tribaloy 700 (PC)	Tribaloy 700 (PC)	300
5	Tribaloy 400 (WD)	Inconel 718	800
6	Tribaloy 800 (PC)	Inconel 718	800
7	Tribaloy 800 (PC)	Aluminized I 718	800
8	Tribaloy 800 (PC)	Stellite 6B	800
9	Aluminized I 718	Tribaloy 400 (WD)	800
10*	Chromized-Carburized Type 304 SS	Aluminized I 718	300
11	Stellite 6B	Aluminized I 718	800
12*	Borided A-286	Borided A-286	300
13*	Chromized-Carburized Type 304 SS	Chromized-Carburized 304 SS	300
14*	Borided A-286	Aluminized I 718	300
15*	Aluminized Hastelloy C	Aluminized Hastelloy C	300
16	Tribaloy 700 (WD)	Tribaloy 700 (WD)	800
17	Tribaloy 700 (WD)	Inconel 718	800
18	Tribaloy 700 (WD)	Aluminized I 718	800

*Couples repeated from Matrix 8
(WD) Weld Deposited
(PC) Plasma Coated

and then tested in the sodium test apparatus in the AI sodium laboratory, to the temperature sequence shown in Figure 4. Testing was completed on December 22, 1973. Data are presently being reduced, and test couples are being removed from the test apparatus for a detailed post-test examination.

The tentative content of the tenth test matrix, which was formulated during the friction program review at AI on November 8 and 9, 1973, is shown in Table 7. This group of specimens will be tested in a sodium vapor environment to a temperature-wear cycle sequence yet to be defined by HEDL. Preparations have begun to obtain the materials required for specimen fabrication. Specific vendors are being contacted by AI in regard to obtaining the application of certain coatings.

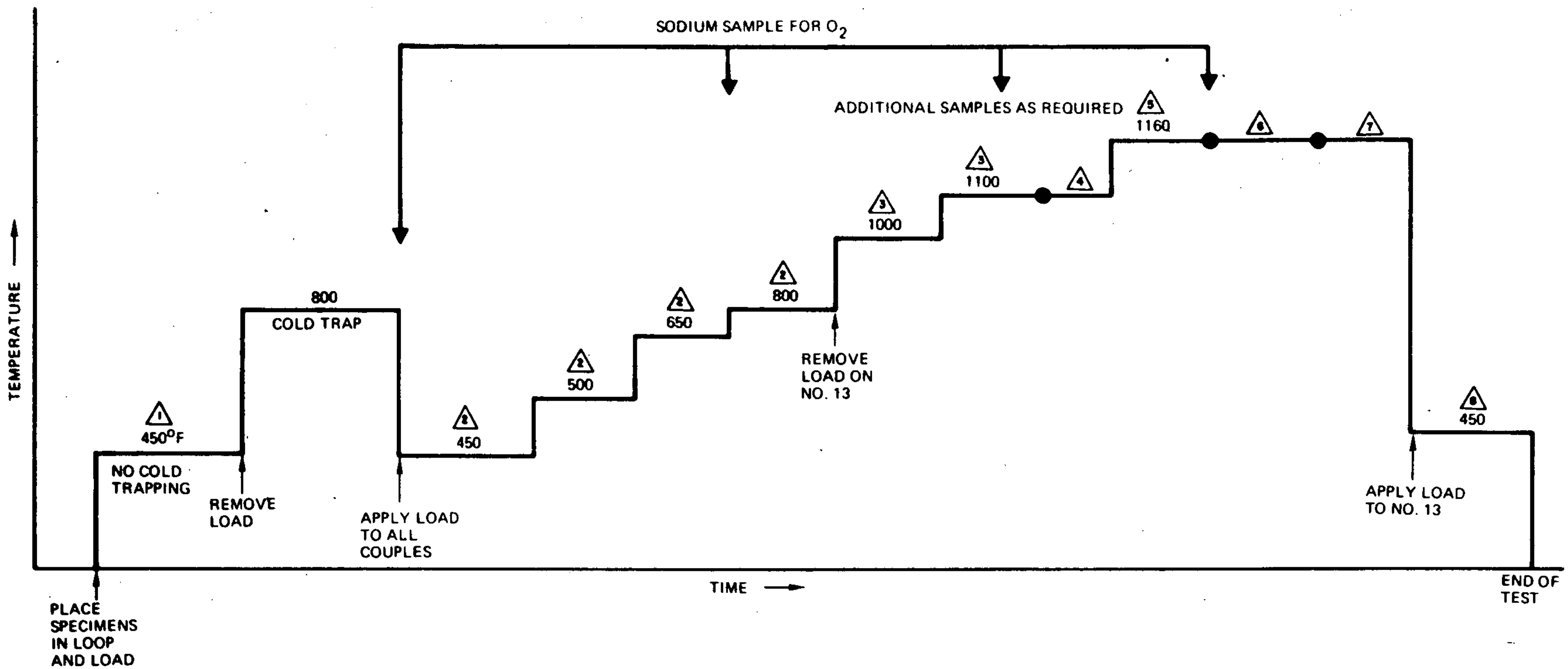
AI presented complete Matrix 8 test data packages to each of the organizations (AEC, HEDL, ARD, AI, LMEC, AMCO, GE, and ANL) represented at the recent friction program review at AI. Vellums or reproducibles and appropriate glossy photographs for this matrix were given to HEDL for inclusion in the interim topical being prepared by HEDL to summarize the results jointly obtained to date by AI, HEDL, ARD, and LMEC.

IV. IMPACT ON LMFBR PROGRAMS

The results of this program are needed for the selection of material for the driver ducts for FFTF and FBR's, and will provide information to define the methods and forces required to clamp a core after refueling. This program will also support LMFBR technology, by providing friction (breakaway and sliding) data at various contact pressures for other reactor component materials and/or material combinations anticipated for use in a high-temperature (400 to 1160°F), high-purity (<5 ppm) sodium and/or sodium vapor environment.

V. NEXT REPORT PERIOD ACTIVITIES

Data from the ninth test matrix will be reduced and evaluated. An account of the results will be published. Test couples for the tenth matrix will be prepared, and testing in a sodium vapor environment will be completed. HEDL will define the content of the eleventh test matrix, and preparation of specimens will be started.



1. APPLY LOAD TO COUPLES 1 THROUGH 6 ONLY, RUB 10 CYCLES
2. AFTER OVERNIGHT DWELL, APPLY 25 WEAR CYCLES
3. AFTER OVERNIGHT DWELL, APPLY 25 CYCLES TO ALL BUT NO. 13
4. AFTER 3-day DWELL MINIMUM, APPLY 25 CYCLES TO ALL BUT NO. 13
5. AFTER OVERNIGHT DWELL, APPLY 25 CYCLES TO NO. 1 THROUGH 12 AND NO. 18; LEAVE LOAD ON NO. 14 THROUGH 17
6. AFTER 3-day DWELL MINIMUM, APPLY 25 CYCLES TO NO. 1 THROUGH 12 AND NO. 18
7. DWELL OVERNIGHT (16-hr MINIMUM) UNDER SPECIFIED LOAD ON ALL BUT NO. 13. DO NOT APPLY ANY WEAR CYCLES
8. AFTER OVERNIGHT DWELL, APPLY 25 CYCLES TO ALL COUPLES

GENERAL TEST CONDITIONS

1. TEMPERATURE CHANGE OF 50°F/hr (MAX.)
2. STABLE TEMPERATURE ±5°F
3. PLUGGING TEMPERATURE AT EACH TEMPERATURE LEVEL
4. O_2 CONTENT TO BE 5 ppm OR LESS THROUGHOUT TEST
5. OVERNIGHT DWELLS TO BE 16 hr MINIMUM

6507-47133A

Figure 4. Temperature Sequence for Ninth Test Matrix

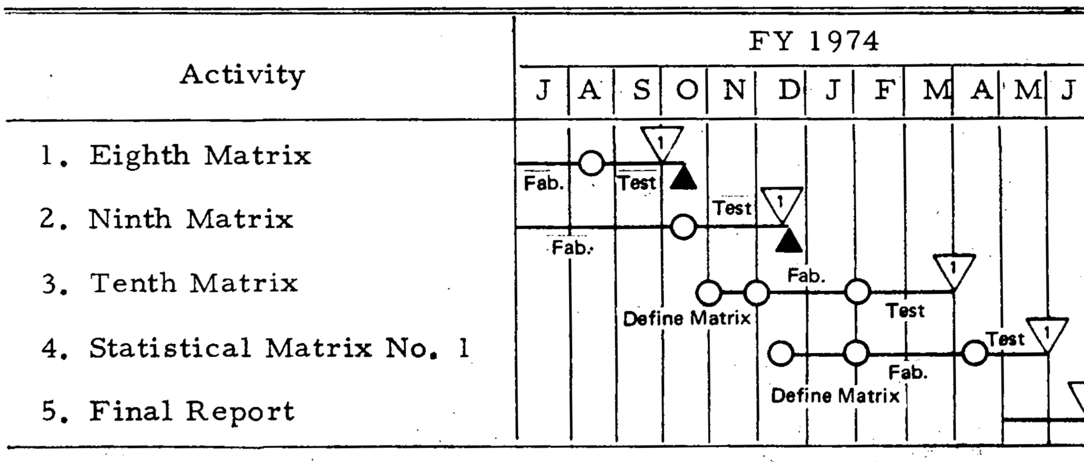
TABLE 7

SODIUM VAPOR TESTS
(Tentative Materials Combinations)

Couple	Rider	Plate	Temperature (° F)	Pressure (psi)
1	Aluminum Bronze	Colmonoy 5	400	200
2	Aluminized I 718	Aluminized I 718	900	800
3	Aluminized I 718	Aluminized I 718	900	200
4	Inconel X-750	Nitrided Type 304 SS	500	200
5	Stellite 6B	I 718	500	200
6	Stellite 6B	Aluminized I 718	500	200
7	Ni-resist	Type 304 SS + Vitrolube	400	200
8	Tribaloy 400	I 718	900	200
9	Tribaloy 700	I 718	900	200
10	Tribaloy 700	Aluminized I 718	900	200
11	K-ramic	I 718	900	200
12	CN-1B	CN-1B	900	200
13	CN-1B	Aluminized I 718	900	200
14	AmCerMet 701-65	I 718	900	200
15	AmCoMo 68-31	AmCoMo 68-31	900	200
16	Stellite 6	Stellite 6	900	200
17	TBD			
18	TBD			

VI. SCHEDULE

A test schedule, showing the anticipated program activities and milestones, is shown in Figure 5.



1. Complete Test
2. Final Test Report

Figure 5. Schedule and Milestones